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An experimental study on the effects of the relative position of a coaxial jet with respect to an externally-imposed transverse acoustic field is presented. A thorough investigation on the effects of chamber pressure, outer to inner jet velocity ratio (VR), and outer to inner momentum flux ratio (MR) on a coaxial jet subject to a fixed transverse acoustic field has been completed by this group [1-3]. However, the jet was located at a pressure node and its location was fixed. The main objective of this study is to investigate the effects on the dark-core length and its standard deviation of varying acoustic pressure and velocity fields at the coaxial jet center. The first resonant transverse frequency for this system is about 3kHz and it is fixed throughtout the study. The chamber reduced presure, Pr, is about 1.5. At a pressure antinode, the maximum p' is about 6% of the chamber pressure. The shear coaxial injector used here is similar to those used in cryogenic liquid rockets. The working fluid for the inner and outer jet and the chamber pressurant is N2 to separate chemistry effects from the effects of a transverse acoustic on non-combusting phenomena such as jet mixing, atomization, and vaporization. Such interactions are thought to play an important role on liquid rocket combustion instabilities. Furthermore, by using a single fluid, ambiguities associated with compostion dependence on mixtures critical properties are eliminated.

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# Coaxial jets at supercritical conditions in a variable transverse acoustic field

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An experimental study on the effects of the relative position of a coaxial jet with respect to an externally-imposed transverse acoustic field is presented. A thorough investigation on the effects of chamber pressure, outer to inner jet velocity ratio (VR), and outer to inner momentum flux ratio (MR) on a coaxial jet subject to a fixed transverse acoustic field has been completed by this group [1-3]. However, the jet was located at a pressure node and its location was fixed. The main objective of this study is to investigate the effects on the dark-core length and its standard deviation of varying acoustic pressure and velocity fields at the coaxial jet center. The first resonant transverse frequency for this system is about 3kHz and it is fixed throughtout the study. The chamber reduced presure, Pr, is about 1.5. At a pressure antinode, the maximum p' is about 6% of the chamber pressure. The shear coaxial injector used here is similar to those used in cryogenic liquid rockets. The working fluid for the inner and outer jet and the chamber pressurant is N2 to separate chemistry effects from the effects of a transverse acoustic on non-combusting phenomena such as jet mixing, atomization, and vaporization. Such interactions are thought to play an important role on liquid rocket combustion instabilities. Furthermore, by using a single fluid, ambiguities associated with compostion dependence on mixtures critical properties are eliminated.

These experiments are carried out at Air Force Research Laboratory (AFRL), Edwards, test cell EC-4. The laboratory setup is shown in Fig. 1. The acoustic oscillations are generated by two piezo-sirens designed specifically for this facility. The two piezo-sirens are located at opposite ends of the chamber. The phase between the excitation signals sent to the two piezo-sirens is variable. By changing this phase the magnitude of the pressure field and the relative position of the coaxial jet center with respect to the acoustic pressure node is varied. Each piezo-siren has a waveguide to transition from a circular cross-section to the test section rectangular shape. An advantage of using these piezosirens is that the acoustics are generated without the introduction of a mean flow in the normal direction to the main injector flow as is the case for alternate acoustics generators. The maximim pressure levels produced by each piezo-siren is ~ 194 dB. The chamber pressure is measured with a Stellar 1500 transducer. To keep the amplitude of the acoustic oscillations to a maximum near the jet, an inner chamber was created (Fig. 1). The inner chamber has a nominal height of 2.6", width of 3" and depth of 0.5". The temperature of the two inner and outer jets of the coaxial injector is controlled independently using three heat exchangers cooled with LN2. A schematic of this injector is shown in Fig. 2. As can be seen from this figure, the inside diameter (ID) of the inner jet is 0.51 mm and the ID of the outer jet is 2.42 mm. The inner jet exit plane is recessed from the outer jet exit plane by 0.25 mm. The inner jet temperature is within ±10K of the critical temperature. The outer jet temperature varies from ~130K and ~190K. The pressures in the chamber range is ~1.5 MPa. The velocity ratio (outer-to-inner jet) varies from 1 to 5 and the momentum flux ratio changes from 0.4 to 10. The coaxial jet is visualized by taking backlit images using a Phantom 7.1 CMOS camera. The images have 128x256 pixels, and each pixel represents an area of about 0.003"x0.003". The framing rate was 41kHz. The exposure time varies from 7-9μs. The jet is backlit using a Newport variable power arc lamp set at 300W. The acoustic pressure is measured using high-speed miniature kulite transducers (CCQ-062-1000A) which have a diameter of 0.062". They are sampled at 41 kHz.

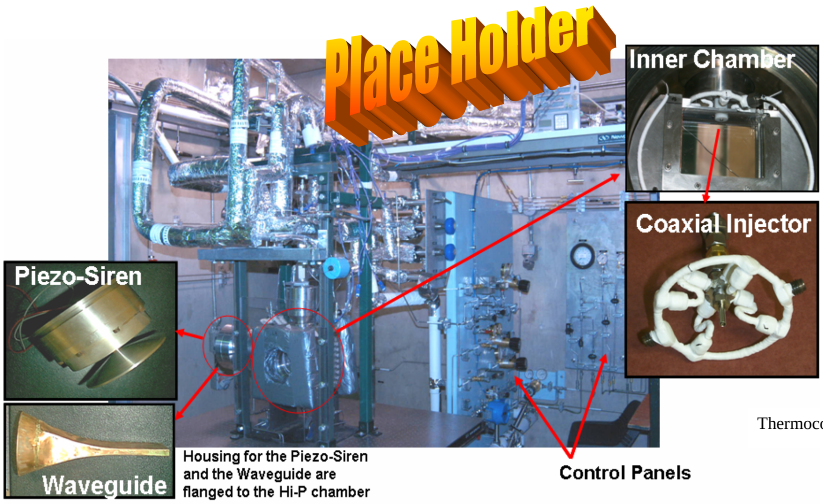


**Figure 1. Supercritical facility at Edwards AFRL (EC-4)**

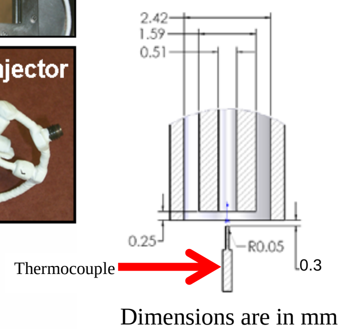


**Figure 2. Injector schematic**

The main parameter used for assessing the impact of the external acoustic field on the coxial jet is the "dark-core" length of the inner jet measured from the high-speed backlit images. A detailed discussion of how the dark-core length is defined and measured has previoulsy been reported [1] and only be brief description will be given here. The original images (Fig. 3A) are first converted, or thresholded, to a black and white image using Matlab's subroutine "im2bw" (Fig. 3B ). The threshold level is determined using the matlab subroutine "graythresh". This subroutine uses Otsu's method [4] and it is based on the zeroth and first cumulative moments of the gray-level histrogram. Once a black and white (b&w) image is obtained, the length of the jet is finally determined by drawing a contour around the b&w image and measuring the axial length of the longest contour attached to the injector as shown in Figure 3C. Two lenghts are defined, the axial length, which is the projection of the total length onto the longitudinal axis and a curved or total length. The curved length takes into acccount the waviness of the jet it is measured using the same contour already used to measure the axial length is divided into a left and a right side (Fig. 3D). The total length is defined as the average of the left and right sides.

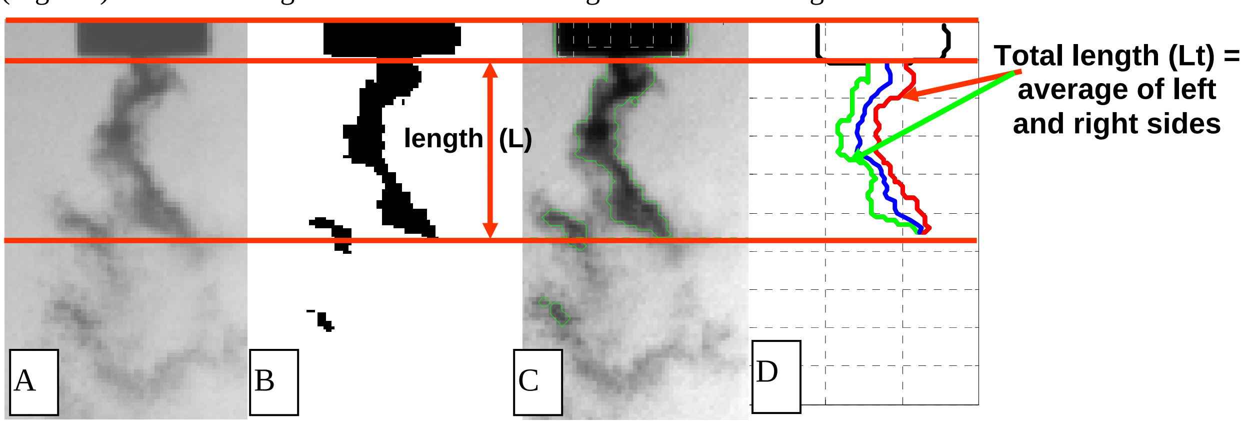


**Figure 3 Measuring the dark-core length. A: original image. B: Black and white image after thresholding. C: Contour used to define axial length (L). D: Schematic of how the total length is computed.**

With only one pizeo-siren in the system, the jet center is aligned with a pressure node. By having two piezo-sirens the location of the node is changed with respect to the center of jet. Fig. 4 shows high-speed measuments of the acoustic pressure in the chamber at Pr=1.5 and Tchamber ~200K but wih the coaxial jet turned off.

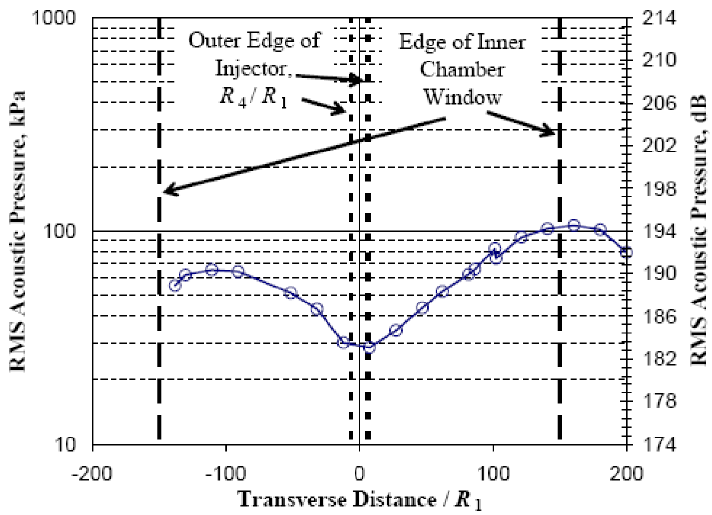



**Figure 4. RMS of acoustic pressure taken at different locations across the length of the chamber.**

Figure 5 shows a qualitative look at the effects of the magnitudes of the acoustic pressure and velocity field on the jet. In this figure the left-most column of jets denotes when the pressure node is almost at the left edge of the chamber and farthest from the jet center. The location of the pressure node divided by the chamber length varies from 0 to 1. Each row of images has the same MR.

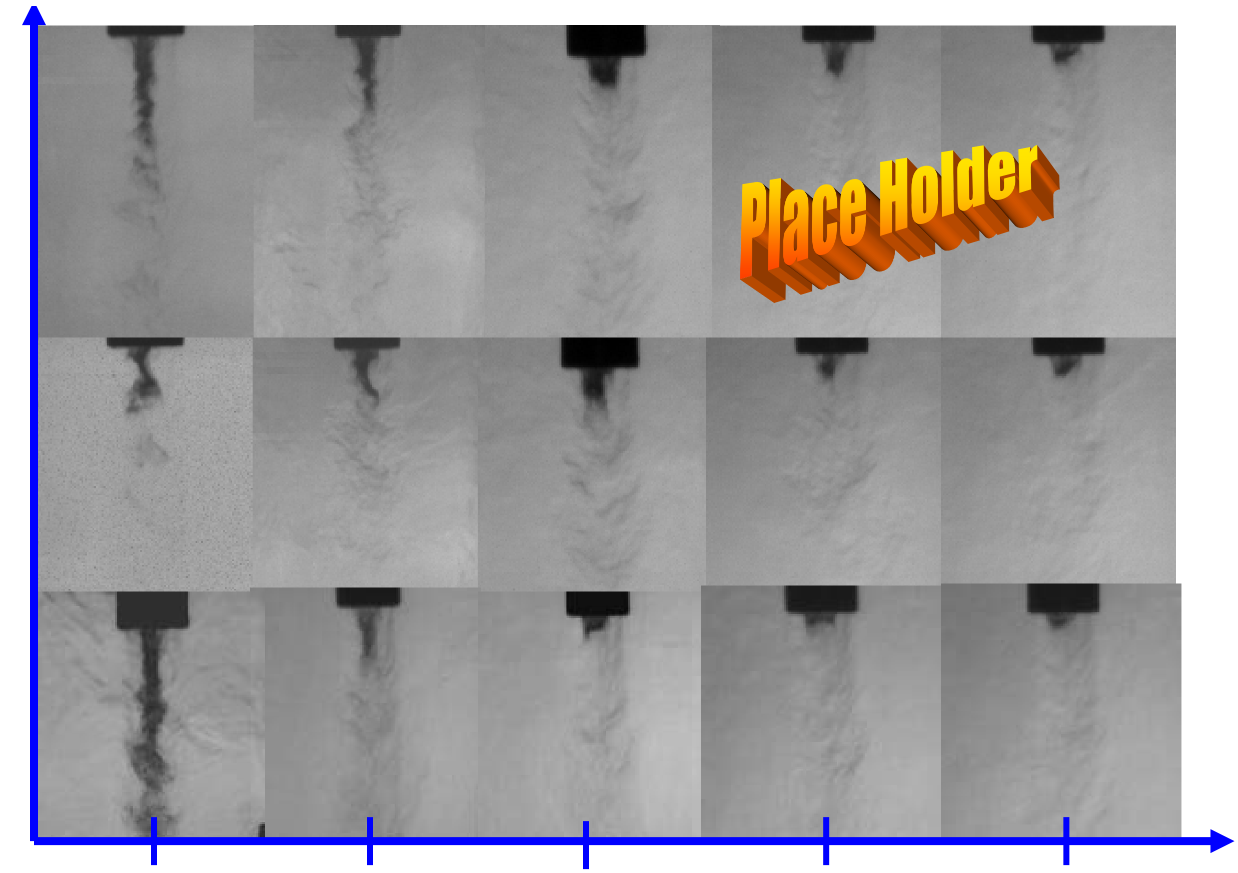


**Figure 5. Collage of high-speed images for a coaxial jet at Pr=1.5 with varying outer to inner jet Momentum Flux Ratio (MR) and also variable acoustic pressure fluctuations.**

Both the axial and curved dark-core length are shown in Fig. 6 and Fig.7 respectively. In these figures, the x-axis is again the position of pressure node/chamber length. Each curve denotes a different MR.

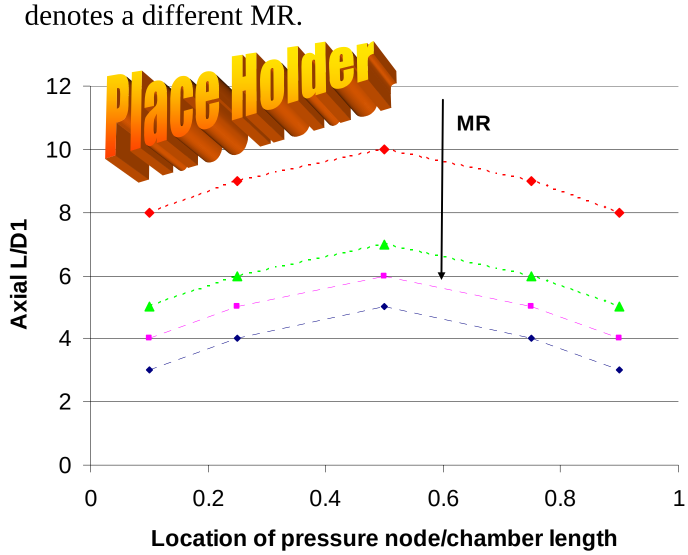


**Figure 6. Normalized axial dark-core length vs. the location of the pressure node with respect to the jet center for varying MR**

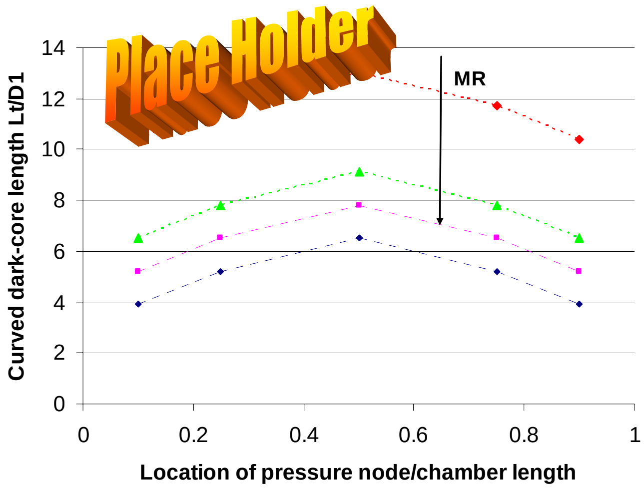


**Figure 7. Normalized curved dark-core length vs. the location of the pressure node with respect to the jet center for varying M**

The concluding remarks will discuss the measured impact of the p' magnitude on the behavoir of both the axial and curved dark-core lengths.

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